Spin valve effect in Si-based spin valve devices with a nano-scale Si channel

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Nano electronics is facing critical issues such as leakage currents and high idling power consumption. The silicon (Si) spin-MOS transistor is a promising candidate to reduce the power consumption utilizing the spin-degree of freedom in semiconductor devices. Recently, spin injection and transport through μm-scale Si channels have been demonstrated by the three-terminal Hanle effect and four-terminal spin-valve effect up to 150 K. However, there is no report on spin transport in nano-scale Si channels, which is vital for realization of nano-scale spin-MOSFETs. The ballistic transport of electrons in nano-scale Si channel is expected to overcome the conductivity mismatch problem between the ferromagnetic (FM) electrodes and Si channel, leading to a higher spin-dependent output. In this research, we systematically investigated the spin transport in nano-scale Si-based spin valve devices. We fabricated spin valve devices with a double layer of Ge (1 nm) / MgO (2 nm) inserted between the Fe electrodes and a 20 nm-long Si channel as shown in Fig. 1(a). Because the Hanle effect cannot be measured in nano-scale Si channels, we employed the two-terminal spin-valve effect to detect spin transport.

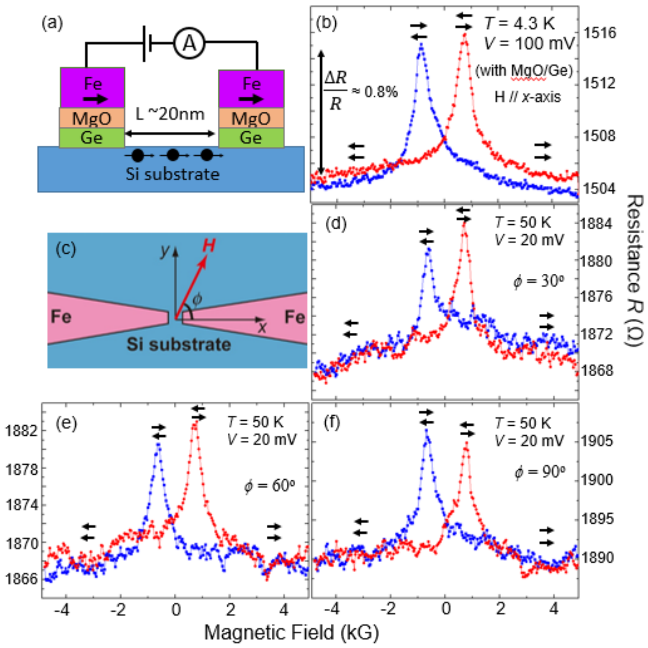

Fig. 1 (a) Schematic structure of our devices. (b) Spin valve effect measured at 4.3 K with a bias voltage of 200 mV. (d), (e), (f) Spin valve signals at 50 K, measured at different in-plain magnetic field direction ϕ with respect to the x-direction, as shown in (c).

Figure 1(b) shows a clear magnetoresistance (MR) with ΔR up to 12 Ω ($\Delta R/R$ = 0.8%) of a device at 4.3 K. From the bias dependence and the temperature dependence of ΔR, we confirmed that anisotropic magnetoresistance (AMR) of Fe electrodes was not the origin of the observed MR. Furthermore, we investigated the dependence of the MR on the magnetic-field direction ϕ with respect to the Si channel direction (Fig. 1(c)) and observed the same MR curves with different ϕ as shown in Figs. 1(d)-(f), indicating that tunneling anisotropic magnetoresistance (TAMR) is also not the origin. These results indicate that the observed MR is governed by spin transport through the nano-scale Si channel. ΔR decreases with increasing temperature but remains observable up to 200 K. The spin-dependent output voltage $(\Delta R/R)V$ is about 13 mV at the bias voltage of 1.7 V, which is among the highest values reported so far.

Reference: D. D. Hiep, M. Tanaka, P. N. Hai, Appl. Phys. Lett. **109**, 232402 (2016).